Coherent Structures in Turbulent Flow over Two-Dimensional River Dunes

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We performed large-eddy simulations of the flow over a typical two-dimensional dune geometry at laboratory scale (the Reynolds number based on the average channel height and mean velocity is 18,900) using the Lagrangian dynamic eddy-viscosity subgrid-scale model [1, 2]. The governing differential continuity and Navier-Stokes equations are discretized on a nonstaggered grid using a second order in time and space curvilinear finite-volume code.

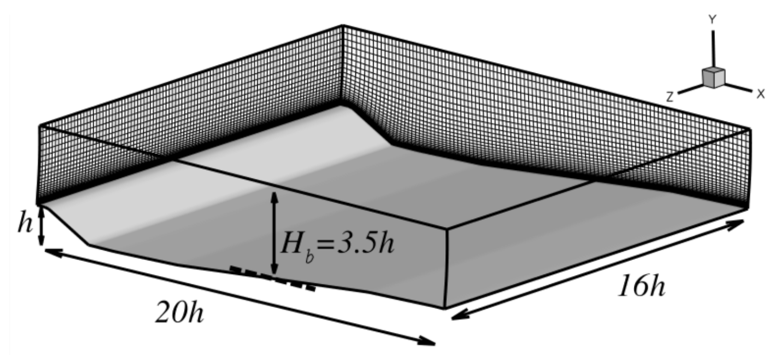

Figure 1: Sketch of the physical configuration. Every fourth grid line is shown.

The computational configuration is sketched in Figure 1. Periodic boundary conditions are used in the streamwise (x) and spanwise (z) directions. At the free surface, the wall normal velocity is set to zero, as are the vertical

derivatives of the streamwise and spanwise velocity components. An orthogonal mesh with $416 \times 128 \times 384$ grid points is used, which results in grid spacings in local wall units $\Delta s^+ \approx 12.9$ (streamwise), $\Delta z^+ \approx 6.0$ (spanwise), and $0.1 < \Delta n^+ < 12.1$ (wall normal).

The flow separates at the dune crest and reattaches downstream on the bed (at $x \simeq 5.7h$) [2]. A favorable pressure gradient accelerates the flow over the stoss-side (the upward-sloping region for $x > 8h$) and an unfavorable gradient for $x < 8h$ decelerates the flow over the lee-side of the dune. Due to the separation of the flow, a shear layer is generated after the crest that expands in the wake region towards the next dune.

In the video, the outer-layer turbulence structures are visualized through isosurfaces of pressure fluctuations colored by distance to the surface. Spanwise vortices are generated in the shear layer separating from the crest due to the Kelvin–Helmholtz instability. They are convected downstream and either interact with the wall or rise to the surface, taking the form of large horseshoe-like structures. These structures may undergo an intense distortion, become one-legged, or be completely destroyed. As they grow to dimensions comparable to (or larger than) the flow depth, a strong ejection occurs between their legs. The interaction between two large coherent structures may result in merging, or in dissipation of the weaker one. Surviving eddies grow and rise along the shear layer emanating from the dune crest; they tilt downward and, eventually, their tips touch the surface. When the legs of the horseshoe are close to the surface, they create an upwelling, which expands and weakens. The legs of the vortex loop remain coherent for a longer time [1, 2].

The video showing the full description of the setup of the problem and the results can be seen at the following URLs:

- Low resolution
- High resolution

This video has been submitted to the Gallery of Fluid Motion 2011 which is an annual showcase of fluid dynamics videos. More detailed analysis on the characteristics of turbulence structures are included in references [1, 2].

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References

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